THE EFFECT OF LIME ON SORGHUM AND WHEAT PLANTS GROWN ON ACID SOILS

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1971

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1980

THE EFFECT OF LIME ON SORGHUM AND WHEAT

PLANTS GROWN ON ACID SOILS

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ACKNOWLEDGMENT

My greatest thanks to God for giving me the ability to make this study possible. Also my greatest appreciation and thanks to Dr. L. G. Morrill, my major adviser, for his patience, encouragement and guidance. My warm appreciation also goes to Dr. Lester W. Reed and Lavoy I. Croy for their advice, comments, and for their service as members of my committee; to Dr. Robert L. Westerman for his service as a member of my committee, too. I would like to express my thanks to Dr. Robert D. Morrison for his help in statistical analysis; to Larry Henderson for his help in bringing the soils of this study from their sites.

I am very grateful to my wife Ftaiem S. Mhaia and my children, Asma, Magla, and Sarah, for their patience and sacrifice for providing me the time for studying.

The author expresses his appreciations to his parents and relatives for their patience during his stay in the United States.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Problems of soil acidity have been extensively discussed among agriculturists in recent years because of the relationship of soil pH to phosphate use efficiency and crop production. Arrhenius (1926) reported that most workers who have previously dealt with soil acidity problems take it for granted that a neutral soil reaction is best for all plants. Such is not the case.

Acid soils are found predominately in high rainfall areas but acid soils may develop anywhere after periods of intensive management for consistent production of high yields. Contributing factors for development of acid soils are the removal of basic cations by leaching or crop production, acidity produced by general microbial oxidative/decomposition processes, and nitrification as indicated by the reaction (Morrill, 1980):

$$2NH_3 + 3O_2 \text{ -- } 2NO_2^- + 2H^+ + 2H_2O$$

Heavy ammonia-type nitrogen fertilization rates, in an effort to obtain near maximum yields, is considered a major contributing cause for development of soil acidity in Oklahoma and U.S.A.

Lowering soil pH increases the solubility and concentration of potentially toxic elements such as Al and Mn.

Al may interfere with Ca, Mg, K, Na, Fe, and P uptake by plants (Foy and Brown, 1963). Black (1968) reported that Al is frequently toxic to plants whenever the soil pH is lower than 5.0. Vlamis (1953) demonstrated a yield reduction with barley by increasing the Al in nutrient solution. Mn toxicities at pH values of 5.5 or below are dependent upon the content of Mn in soil and parent materials. Mn toxicities may also be a result of reducing conditions created by flooding (Foy, Chaney, and White, 1978).

High nitrogen fertilization rates in Oklahoma without consistent use of Ag-lime ($CaCO_3$) or use of nitrogen fertilizers with $CaCO_3$ as filler has lowered soil pH values from 4.8 to 4.2 on many light-textured wheat producing soils. The intensification of soil acidity and associated problems justified the initiation of two greenhouse experiments with two acid soils to study the effects of lime application on soil test values for Ca, Mg, K, Fe, P, and Al and the plant contents associated with winter wheat TAM 101, Triticum aestivum, L.

CHAPTER II

REVIEW OF LITERATURE

Soil Acidity

Soil acidity is defined as "a system proton yielding capacity in going from a given state to a reference state" (Jackson, 1958, p. 6). Soil acidity involves intensity and quantity aspects. The intensity aspect is usually known as the hydrogen ion activity, expressed as a pH value. The quantity aspect is characterized by the amount of an alkali required to neutralize the acidity to an arbitrary end point (Black, 1968).

Soil acidity also involves two kinds of acidity, exchangeable and titratable. The exchangeable acidity is that portion of soil acidity that can be replaced with neutral, unbuffered salt such as KCl, CaO_2, or NaCl. The titratable acidity is that amount of acidity neutralized at a selected pH, which often is 8.2 (Pearson, 1967).

Development of soil acidity involves many factors and is intensified as time passes on. One of the most important factors in the development of soil acidity is high annual precipitation over evaporation. Soils that receive 35 to 50 cm annual precipitation in Central United States contain smaller amounts of soluble salts, such as calcium carbonate and gypsum in the surface layers compared to those receiving less annual precipitation (Black, 1968).

High application of nitrogen fertilizers, prolonged basic cation removal by cropping and industrial pollution with acid-forming gases were other deciding factors in intensifying soil acidity (Desai and Subbiah, 1951; Fouth, 1978).

During the 1950's and early 1960's the relationship between Al and soil acidity was studied extensively and established that Al was absorbed by clays, not only as an exchangeable monomeric trivalent ion, but also as hydroxy-Al polymers of indefinite size and degree of hydration (Jenny, 1961; Pearson, 1967). Many workers had been convinced that Al ions in soil were the main source of acidity, in addition to hydrogen ions. For example, Jenny (1961) and Veitch (1902) stated that both Al and H ions were identified on the exchange sites of clay minerals. The release of H ions into the soil solution is related to the soil acidity until the pH value of the soil reached 5.0. Beyond this level, Al ions will be displaced from clay minerals by H ion and readsorbed on clay minerals as exchangeable cations (Miller, 1965; Jonghorbani et al., 1975; Regland and Coleman, 1960; Frink and Peech, 1963; Jackson, 1963a,b). In acid soils, Al and H ions exist in equilibrium. H ions dissolve some Al from the clay mineral lattice. In base unsaturated system, the addition of more base makes the Al undergo hydrolysis with the production of H ions equivalent to the amount of Al present (Frink and Peech, 1963). Bear (1964) in his book, Chemistry of the Soil, proposed the method of hydrolysis of hydrogen as a result of presence of Al ions in acid soils as follows:

$$Al^{+++} + H_2O \longrightarrow Al(OH)^{++} + H^+$$

$$Al(OH)^{++} + H_2O \longrightarrow Al(OH)_2^+ + H^+$$

$$Al(OH)_2^+ + H_2O \longrightarrow Al(OH)_3 + H^+$$

Therefore, presence of Al ions in soil solution is responsible for low pH values and high buffer capacities of soils.

Under acid conditions, hydrated Al ions are considered toxic and an acid in the general sense (Black, 1968). This includes exchangeable Al (Veitch, 1902). Al bound by organic matter contributes a significant part to extracted-Al from the soil surface by neutral salts such as in KCl and $LaCl_3$ (Bloom, McBride, and Weaver, 1978). Vlamis (1953) and Foy (1974) stated that Al ions often were associated with low pH value in soil and hence, the Al toxicity to plants occurred at pH values below 5.0, but it could occur at pH values as high as 5.5.

Numerous research workers reported that Al toxicity symptoms for plants were similar to those of a P deficiency. In general, Al toxicity symptoms for plants are stunted roots and small tops, accompanied with yellowing of the leaf tips of plants. The roots suffering from Al toxicity are short, stubby, thick, and irregular in shapes (Foy, 1974; Munn, 1976; Berg, 1976; Abruna, 1970).

As far as the physiological effects on plants are concerned, Al was found to be involved in controlling respiration and increasing the cell wall rigidity (Foy, 1974; Rorison, 1965). However, Al reduced nutrient uptake and interfered with translocation mechanisms of nearly all elements absorbed by Al sensitive plants (Villagarcia, 1976; Stahlberg, 1976). Sometimes a high concentration of Al inhibits Ca and P uptake, but induces a high Mn uptake by plants (Boyer, 1978; Foy, 1974). The reduction of Ca and P uptake by plants caused by Al is explained on the basis of accumulation of Al in roots. Accumulation of Al in roots may result in inhibition of root elongation and cell division of root epidermis (Matsumoto et al., 1976).

Plant species and varieties were found to differ widely in tolerance to Al toxicity in growth media (Foy, 1974 and 1976). Many crops, such as barley and wheat, are tolerant to Al as a result, either from their ability to adapt to soil acidity, or to their ability to raise pH near their root surfaces (Foy, 1976; Martini et al., 1977; Burns et al., 1964). Tolerance of plants to Al toxicity was found to coincide with their ability to tolerate low P in nutrient solutions. Tolerance of some cultivars of tomato, barley and corn was associated with P use efficiency of these plants (Clark, 1974; Foy, 1974 and 1975).

Two approaches are used to assure that plants will grow without serious inhibition from unfavorable soil pH: (1) Plants are selected to grow well in existing soil pH, or (2) the soil pH is altered to suit the preference of plants (Foth, 1978). The literature indicates that soil pH adjustment is the solution most commonly used.

In addition to Al toxicity to plants, anhydrous ammonia and other ammonium N applications to soil caused injurious effects and P deficiency symptoms to corn plants. The injuries were severe with shallow application of anhydrous ammonia (Colliver and Welch, 1970). Urea is also an injurious nitrogen carrier, especially in alkaline soils. Cook (1962) found that urea applications to soils caused damages to seedling roots of corn as a result of the release of ammonia from hydrolysis of urea. Court, Stephen and Waid (1962) also reported that phytotoxity to seedlings could occur soon after application of urea to soil. They speculated that phytotoxity was due, at least in part, to the accumulation of ammonia produced by urea hydrolysis and accumulation of nitrate at later time.

Tisdale and Nelson (1975) reported that although monoammonium

phosphate (MAP) and diammonium phosphate (DAP) have the advantage of being high plant-food carriers, they can cause seedling injury and root deleterious effects, especially in alkaline and coarser-textured soils.

Neutralization of Soil Acidity

Soil acidity is usually neutralized by addition of limestone or other Ca containing bases. Limestone was discovered long before basic or acidic reactions of soil were noted. The use of lime in agriculture goes back, at least, to the beginning of Christian Era (Dorsey, 1952). The main materials used to neutralize soil acidity are: calcite, aragonite, dolomite and magnesite (Boynton, 1966). The soil neutralizing reactions of calcite with soil acids are complex (Pearson, 1967). Neutralization rate and the final reaction products are not known with certainty. Factors such as particle size of liming materials and their reactivity are found to affect the reactions that occur (Coleman et al., 1954).

Many reasons are given for the addition of lime to acid soils. Frequently, lime is added to acid soils to reduce acidity to favor plant growth, to reduce the solubility of toxic elements, such as Al and Mn, and to increase the availability of plant nutrient elements such as P, Ca, K, Mg, and Fe (Bear, 1969).

Effect of Lime on Ca, Mg, and K

The effect of lime application on increasing yield and growth of plants has been reported often in the literature. Addition of Ca, Na, and K hydroxides to acid soils resulted in a three-fold yield increase

of wheat and barley (Lafever et al., 1977; Kauffman, 1978). Lime application to acid soils was found to increase availability of all basic cations (Agruna et al., 1964; Conroy and Lambe, 1962). Brady (1974) reported that addition of liming materials to acid soils was intended to increase the exchangeable Ca, Mg, and might increase K in addition to increasing base saturation of the limed soils.

Since addition of lime materials has an effect on the availability of nutrients in soils, plant nutrient content will be expected to increase with the increase of nutrient availability in soils and vice versa. Addition of lime to acid soils reduced Mg and P contents in grasses, while Ca contents increased significantly (Abruna et al., 1964). Leibig (1847) believed that liming soils makes K more available for plant growth, while, MacIntire (1930), an authority on K and Ca relationships, writes just the opposite.

Overliming of acid soils has many effects on plant growth and nutrient availability. Liming of acid soils up to neutrality or beyond may depress the exchangeable Mg and make the soil deficient in Mg for some plants (Khan, 1970) and depress K availability as well as Mg, according to Russell (1973). Knight (1938) reported that it was advantageous to regulate the application of lime so that the reaction of the soil would be maintained near neutral point, or close to pH 6.5.

Effect of Lime on Al, Fe, and P

There are numerous forms of P in soils. In the normal soil pH range, P is found as orthophosphate, $H_2PO_4^-$ and $HPO_4^=$, which are the most stable and dominant forms of phosphates in soil solutions (Dixon and Weed, 1977). Addition of superphosphate with lime to acid soils

reduced the recovery of applied P by plants, but was corrected by application of high P levels (Neller, 1953; Lawton and Davis, 1956). P may form sparingly soluble calcium phosphate, which reduces the P uptake by plants (Munns, 1965; Amarasiri and Olsen, 1973). Neutralization of soil exchangeable Al by liming materials results in more efficient P uptake from Utisols and Oxisols (Fox et al., 1964; Woodruff and Kamprath, 1965; Reeve and Sumner, 1970). Liming equivalent to the amount of exchangeable Al X 1.5 represents a realistic approach to neutralize most of the exchangeable Al and reduce the Al saturation of the effective CEC (Kamprath, 1970; Mundez and Kamprath, 1978). P application, alone or in combination with lime, was found effective in the elimination of Al toxicity and correction of P deficiency in plants (Munns, 1965; Pierre and Stuart, 1933). This was explained on the basis of a pH increase and precipitation of Al as Al-phosphate (Pierre and Stuart, 1933). For example, liming an aluminous ferrogeneous latosol to pH 7, markedly decreased the sorghum P uptake as a result of high concentration of Ca ions that formed insoluble Ca-phosphates (Fox et al., 1964). Dekalb loam soil, limed approximately to pH 6.5 and 7.0, resulted in P starvation and disturbance of corn plants with marked injury (Pierre and Browning, 1935). A combination of lime with P applied to an acid sandy soil increased P uptake by subterranean clover because lime prevented P from being leached (Paton and Loneragan, 1960). High application of P reduced the Fe uptake by Red Kidney Bean from nutrient solution (Rediske and Beedulf, 1953). Thorne, Wann and Robinson (1950) concluded that high P, causing a precipitation of Fe in soils or plants, was a general cause of lime-induced chlorosis. High lime, and high soil

pH did not prevent Fe uptake but apparently helped in inactivating Fe within plants.

Effect of Lime on Soil Microorganisms

Soil reaction has a direct effect on many soil organisms as well as on higher plants. A soil reaction in the range of pH 6.0 to 8.0 is considered the most favorable range for common agricultural plants (Knight, 1938). Bacteria which carry out nitrification were not active in soils with pH values less than about 5.0 (Russell, 1950). Norman (1956) also noted that the rate of nitrification was higher in soils with high lime content than in strongly acid soils.

Liming can affect both symbiotic and nonsymbiotic nitrogen fixation in the soil. Black (1957) reported that Azotobacter would not fix nitrogen below pH 6.0. Nitrogen fixation by legumes also was markedly influenced by soil reaction. For instance, nitrogen content of soybeans was found to increase regularly with calcium saturation in the case of two mineral soils (Mehlich and Colwell, 1943). Increasing the Ca status in nutrient solution with calcium sulfate resulted in the nodulation of all Trifolium subteraneum L. Var. Becch Marsh plants (Loneragan and Dowling, 1958). Albrecht (1933) stated that the degree of soil acidity was responsible as an environmental factor for nodulation failure for soils with a pH of 5.0 and lower. Nodulation failure was brought about, not so much by the degree of acidity, as by the deficiency of the available Ca in the soil.

Soil reaction was also found to affect the population of autotrophic ammonium oxidizing organisms in soils. The population of autotrophic ammonium-oxidizing organisms was greater in neutral and alkaline

soils than in acid soils (Morrill, 1961; Wilson, 1928). In another study by Keyser and Munns (1979), the growth of most strains of cowpea rhizobia was stopped by acidity.

Effect of Excess Lime on Plant Growth and Availability of Mn, Zn, Cu, and B

Detrimental effects on plant growth was characterized by a chlorotic condition because of Mn deficiency (Gilbert, 1928; Munn, 1930; Pettinger et al., 1932; Willis, 1928; Knight, 1938). Liming soils to pH 6.4 or above decreased growth and Mn plant content reflecting the decreased Mn availability (Sanchez and Kamprath, 1959). Overliming injuries were speculated from the deficiency of Fe, Zn, and Cu, as well as Mn. Liming soils to pH levels above the level required for optimum growth, lowered availability of many elements such as Fe, Mn, Cu, and possibly B (Knight, 1938; Naftel, 1937). Kamprath (1970) and Russell (1973) reported that B deficiency in soils was a result of B adsorption by Al-hydroxy and hydroxy-Fe soil components. Purvis and Davidson (1948) also stated that when soil reaction reaches or exceeds neutrality, availability of B decreases. In many occasions, crop growth is reduced by liming of soils even when pH is considerably below 7.0 (Pierre and Browning, 1935).

CHAPTER III

METHODS AND MATERIALS

Sorghum Experiment

A greenhouse study was conducted at Oklahoma State University Soil Fertility greenhouse in 1979. The soil type, location, initial pH, crop grown and treatments are shown in Table I.

The sorghum experimental layout was set up as a 6 x 6 latin square design with two levels of phosphorus, 20 lb/A and 60 lb/A P_2O_5 and three levels of effective calcium carbonate equivalent (ECCE), no lime, 0.7 and 1.4 tons/A $CaCO_3$. The design was suggested by Dr. Morrison (1978) to minimize differences caused by air movements in the greenhouse. An additional row was added around the treatment to minimize edge effects.

The lime levels were added to treatments as pure finely grown $CaCO_3$. Each lime allowance for each lime treatment container was spread over 3 kg soil on a plastic sheet and mixed thoroughly by sifting the soil between hands and fingers 10 times. No equilibration time was allowed before planting.

Sources used to supply N, P, and K were urea (46-0-0), K_2HPO_4 (0-41-53.8) and KCl (0-0-62.9). N and K were supplied to treatments, after addition of lime, at a rate of 180 lb/A N and 152 lb/A K_2O, respectively, in solution form. The N and K and P allowance for each treatment was added by spraying the solution on the 3 kg soil on a

TABLE I

SOIL LOCATION, CLASSIFICATION, pH, CROP GROWN, RATE OF LIME (ECCE) AND PHOSPHORUS

	Location	Soil Classification	Crop Grown	Rate of Lime ECCE** Lime of Phosphorus
Expt. 1	Carrier	Pond Creek, silt loam, Udic Argiustoll with pH of 5.3	Forage Sorghum (Sorghum bicolor L.)	$L_0^*P_1^*$ = no lime + 20 lb/A
				L_0P_2 = no lime + 60 lb/A
				L_1P_1 = 0.7 T/A + 20 lb/A
				L_1P_2 = 0.7 T/A + 60 lb/A
				L_2P_1 = 1.4 T/A + 20 lb/A
				L_2P_2 = 1.4 T/A + 60 lb/A
Expt. 2	Waurika	Enterprise, fine silt loam, Typic Ustochrept with pH of 5.1	Winter Wheat (Triticum aestivum, L.)	L_0 no lime
				L_1 365 lb/A
				L_2 520 lb/A
				L_3 545 lb/A
				L_4 1023 lb/A
				L_5 1500 lb/A

*ECCE = Effective calcium carbonate equivalent

** L = Designate rate of lime T/A or lb/A and P = Designate of phosphorus as lb/A P_2O_5

plastic sheet using a hand sprayer and mixing thoroughly by sifting the soil between hands and fingers. The process was continued until the N and K allowances were met. Afterwards, the soil treatments were potted in a size No. 10 can, lined with a 9" X 14" plastic bag.

The whole experiment was placed over a plywood table near the center of the greenhouse. Each can of each treatment was placed on top of another can of the same size to minimize differences in air circulation among the pots.

The moisture content of the treatments was kept at approximately 12.5%, using a scale to determine the amount of water to be added every other day (Terman et al., 1960).

On November 15, 1978, five seeds of forage sorghum Sugar Drip Sorgo, variety Sorghum bicolor, L., Moech were sown in each pot. The five seeds were equally spaced in each pot using a hard board template with equally-spaced holes for seed placement.

One week after germination and seedling emergence the seedlings were thinned to the three best seedlings per can.

On January 15, 1979, the plant tops were harvested using scissors and placed in paper bags for fresh and dry weight determinations. Soil samples were collected from all pots in each treatment and placed in plastic bags for chemical analysis.

Wheat Experiment

A second greenhouse study was conducted during the end of year 1979 and beginning of year 1980 at the Oklahoma State University Soil Fertility greenhouse. The soil type, location, initial pH, crop grown and treatments are also shown in Table I.

The experimental layout for wheat was set up as a 6 X 6 latin square design with six levels of effective calcium carbonate equivalent (ECCE). The levels were 365 lb/A, 520 lb/A, 545 lb/A, 1023 lb/A and 1500 lb/A $CaCO_3$. An additional row was placed around treatments to minimize edge effects. The whole experiment was located in the same place as the sorghum experiment on the same plywood table. Application of lime was made in the same manner as in the sorghum experiment.

Since the Enterprise soil had more than sufficient amount of P and K, according to the Oklahoma State University Soil Testing Lab, no P and K were supplied to the treatments, N and Ca being the only variables. N was applied at a rate of 90 lb/A N in the form of a urea (46-0-0) solution added to each can with irrigation water. The treatments were potted in No. 10 size cans, lined with 9 X 14" plastic bags.

On November 25, 1979, nine seeds of TAM-101 winter wheat variety were sown in each pot. The nine seeds were equally spaced in each pot using a hard board template with equally spaced holes.

One week after seedling emergence, seedlings were thinned to the best five.

Soil moisture in the experiment was kept adequate observing the moisture distribution in a side punched, size No. 10 can included in the south border row of the experiment. Whenever the soil moisture distribution fringe retreated from the soil surface in the pot, 500 ml distilled water was added to all cans in the experiment.

On January 24, 1980 after 60 days, the wheat tops of each pot in each treatment were harvested and placed in paper bags for determination of fresh and dry weights. The wheat roots of each pot in the experiment were carefully collected and dipped in distilled water three times to

remove attached soil particles, then placed in paper bags for determination of fresh and dry weights for each can.

Laboratory Procedures

Soil Samples

Soil samples of both sorghum and wheat experiments were labeled and submitted to the Oklahoma State University Soil Testing Laboratory for routine analysis, which includes determination of soil pH, buffer index and soil test for N, P, and K. Additional determination of soil Ca, Mg, and K for each pot in each treatment were made. A ten gram air-dry soil sample for each pot in each experiment was saturated with 50 ml of 1 N ammonium acetate. The soil samples were shaken for ten minutes. Each soil sample then was filtered with Whatman's No. 42 filter paper with light suction and washed with two consecutive 50 ml volumes of 1 N ammonium acetate. Ca, Mg, and K were determined in the leachate for each soil sample leachate to prevent interference from phosphates and sulfates in the flame emission (Black, 1965).

The exchangeable Al was extracted by 1 N KCl, prepared by dissolving 74.55 g of KCl in one liter distilled water. A ten gram air-dry soil sample was taken for each pot in the experiment and saturated with 100 ml of 1 N KCl. The soil samples were filtered with Whatman's No. 42 filter paper. Exchangeable Al in the soil sample leachates was determined using a 403 Perkins-Elmer Atomic Absorption Spectrophotometer. In the determination of exchangeable Al, 1% by volume of 5% $LaCl_3$ was added to each soil sample leachate to prevent interference from phosphates and sulfates in flame emission (Black, 1965).

Plant Samples

The harvested sorghum plant tops were placed in labeled paper bags. Fresh weight of plant tops for each can in the experiment was determined using a sensitive, digital, electronic balance to the nearest 0.01g. Dry weight of the plant tops was also determined after the plant tops were dried in an oven for 24 hours at 65°C using the same balance as for wet weight determinations.

Harvested wheat plant tops and roots were placed in labeled paper bags separate from each other. Fresh weight and dry weights for wheat plant tops and roots were determined as for sorghum above. After drying, wheat plant tops and roots were finely ground using stainless steel Spex Mixer/Mill, and kept in labeled plastic bags (each can) for chemical analyses.

Ca, Mg, K, Fe, and Al contents for wheat plant tops and roots were determined separately by placing 0.10 g of dried, finely ground plant tissue sample from each treatment in a beaker with five ml of concentrated HNO_3, followed by 2 ml of concentrated $HClO_4$. The samples were heated to 100°C until the plant material was digested and a straw-yellow color was obtained in the digestion solution. The beakers were covered with watch glasses, and the temperature raised to 175°C and maintained until a pale yellow color appeared. Ten to 15 ml of the 3:1 nitro-perchloric acid mixture was added and samples were reheated until only 0.5 ml sample digest remained.

The beakers were removed, cooled and 25 ml distilled water added. The samples were transferred into 50 ml volumetric flasks. The beakers were rinsed with an additional 10 ml distilled water poured into the volumetric flasks, which were then filled to volume. Ca, Mg, K, Fe, and

Al were determined using a 403 Perkins-Elmer Atomic Absorption Spectrophotometer. In determination of Ca, Mg, K, Fe, and Al contents of wheat tops and roots, 1% by volume of 5% $LaCl_3$ was added to each digested sample to prevent interference from phosphates and sulfates in flame emission (Reed, 1980).

P content in wheat tops and roots was determined by taking 5 ml samples from the previously digested top and root supernatant samples in a 100 ml volumetric flask. Twenty ml distilled water was added to each sample; and solution was mixed and 5 ml of sodium molybdate added. Five ml of hydrazine sulfate then was added to each sample to develop blue color. The volume of the samples were transferred to conical flasks, heated and boiled for one minute. Samples were then cooled and read on a Turner No. 330 Spectrophotometer at 660 nanometers. P content in wheat tops and roots was then determined using the P-standard curve of absorbance against concentration.

The sodium molybdate reagent was prepared by dissolving 20 g of reagent grade sodium molybdate in 600 ml of distilled water. This solution was added to 400 ml of concentrated perchloric acid. The hydrazine sulfate reagent was prepared by dissolving 20 g of reagent grade hydrazine sulfate in about 20 ml distilled water using heat. This solution was diluted to 1 liter final volume (Reed, 1980).

CHAPTER IV

RESULTS AND DISCUSSION

Sorghum Experiment

Fresh and Dry Weight of Sorghum Tops

Application of 0.7 and 1.4 tons/A rates of effective calcium carbonate equivalent (ECCE) as prescribed by soil test for a buffer index, B.I. 6.8, to Pond Creek silt loam soil decreased the fresh and dry weight of sorghum tops, regardless of phosphate levels (Table II and Figures 1 and 2). Fresh and dry weights of sorghum tops were higher at 0.7 tons/A lime rate with 60 lb/A P_2O_5 rate than with 20 lb/A P_2O_5 rate indicating that phosphate availability was affected by lime application.

An increased yield with 60 lb/A P_2O_5 compared to the 20 lb/A with no lime applied indicates that low yields on this soil when the pH is low involves P availability.

The statistical analysis of the data collected in this greenhouse experiment showed that the reduction in fresh and dry weights of sorghum tops was significant at 0.01 level of probability (Table III). Comparison of means with LSD values indicate that most of the change occurred with application of 0.7 tons/A lime rate (Table II, Figures 1 and 2).

Phosphorus rates applied to Pond Creek silt loam soil in combination with lime rates increased the fresh and dry weight of sorghum tops

TABLE II

MEANS OF FRESH AND DRY WEIGHTS OF SORGHUM TOPS: EXCHANGEABLE Ca, Mg, Al, AND SOIL REACTION OF POND CREEK SILT LOAM SOIL AFTER TREATMENT WITH PHOSPHORUS AND LIME

Treatments		Fresh Weight of Tops of Three Plants (g)	Dry Weight of Tops of Three Plants (g)	Exchangeable Calcium (ppm)	Exchangeable Magnesium (ppm)	Exchangeable Aluminum (ppm)	Soil Reaction (pH)
P_2O_5 (lb/A)	ECCE (Ton/A)						
20	0.0	5.3*	1.3	568	211	18	4.6
20	0.7	0.8	0.3	791	224	15	5.0
20	1.4	0.8	0.2	898	197	13	5.4
60	0.0	10.4	2.2	566	213	25	4.6
60	0.7	2.9	0.7	761	214	18	4.8
60	1.4	0.8	0.2	895	196	13	5.8
LSD (0.05)		2.5	0.5	73	n.s.	7	0.1

*Means of 6 treatments.

n.s. - not significant

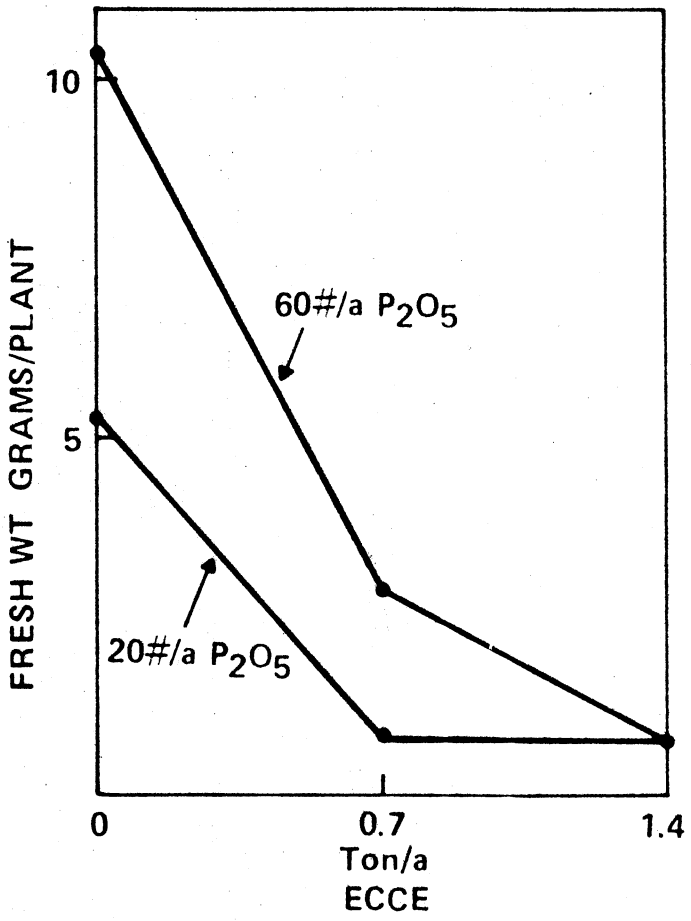

Figure 1. Effect of Lime and Phosphorus Rates on the Fresh Weight of Tops of Sorghum Plants Grown on Pond Creek Soil.

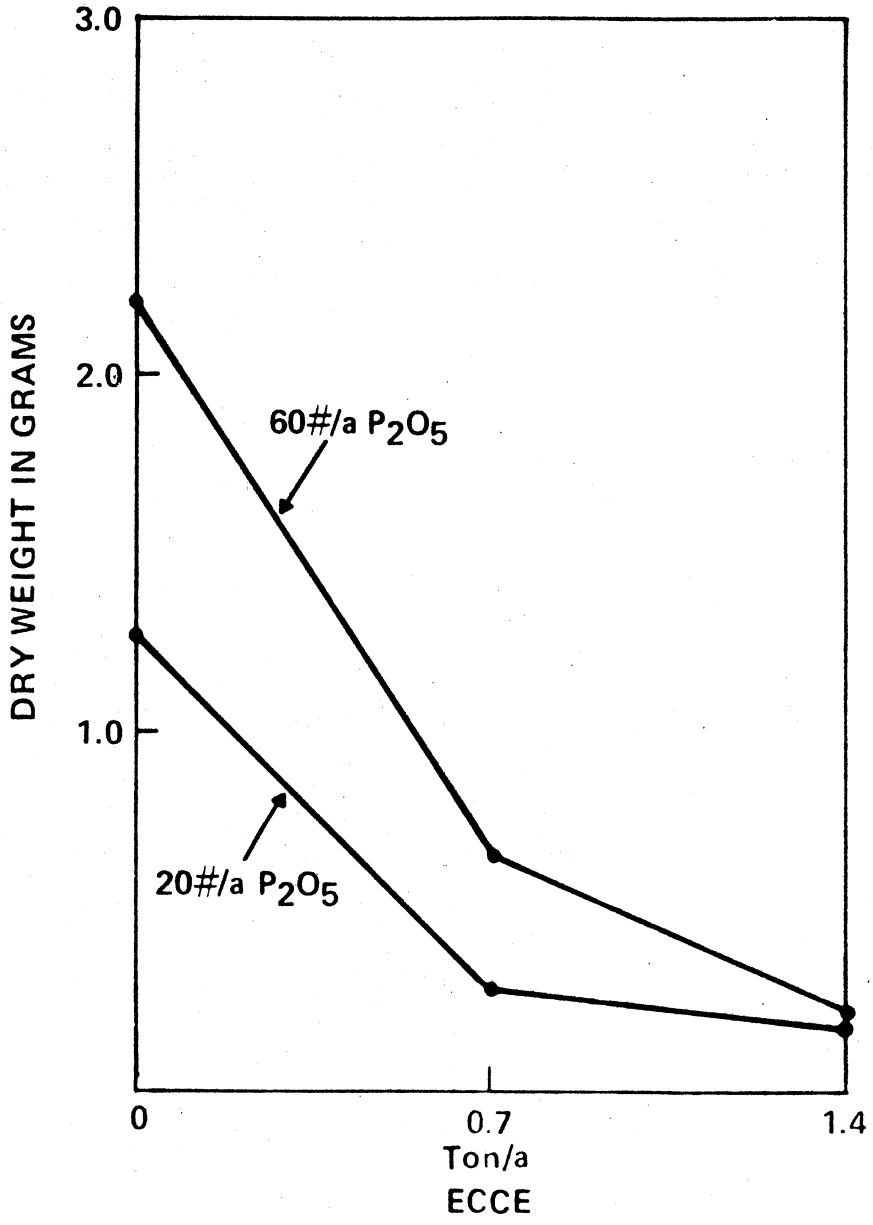

Figure 2. Effect of Lime and Phosphorus Rates on Dry Weight of Tops of Sorghum Plants Grown on Pond Creek Soil.

TABLE III

MEAN SQUARES FOR FRESH AND DRY WEIGHT OF SORGHUM TOPS; EXCHANGEABLE Ca, Mg, Al, AND SOIL REACTION OF POND CREEK SILT LOAM SOIL AFTER LIME AND PHOSPHORUS TREATMENT

Source of Variation	d.f.	Fresh Weight (g)	Dry Weight (g)	Exchangeable (ppm)			Soil Reaction pH
				Ca	Mg	Al	
Rows	5	3.273	0.212	8969.444	1407.213	31.111	0.027
Columns	5	5.815	0.238	1449.444	222.906	44.444	0.014
Phosphorus	1	51.505**	1.760**	1225.000	96.694	100.000	0.007
Lime	2	173.577**	7.899**	333002.778**	1549.628	211.111*	2.176**
PhosphorusXLime	2	19.711*	0.588*	758.333	114.588	33.333	0.084**
Error	20	4.444	0.148	3636.111	592.542	37.778	0.010

*Significant at 0.05 level of probability.

**Significant at 0.01 level of probability.

significantly at 0.01 level of probability (Table III). Comparison of means with LSD values indicate that the 60 lb/A P_2O_5 was responsible for an increase in fresh and dry weight of sorghum tops. This increase in fresh and dry weights is interpreted to indicate that liming reduced the availability of soil P, and that P availability was more restrictive in crop production than the other negative factors associated with this soil.

Statistical analysis of this experiment also showed a significant interaction between lime and phosphorus treatments at 0.05 level of probability (Table III). The interaction has not been explained due to the lack of sensitivity of this experiment, but P availability is affected by lime application to this soil in the greenhouse.

The experimental result obtained for yield versus lime application in this greenhouse experiment was totally unexpected and is in opposition to field results obtained on this and similar soils by Westerman and his associates (1980), even when they applied higher rates of lime. This forces a critical examination of the greenhouse procedure used, though it is essentially that prescribed by Terman, Allen, and Clements (1966) from their extensive greenhouse investigations at the National Fertilitizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama. The procedural exception noteworthy is a 10 to 14 day reaction period of lime with moistened soil prior to planting allowed by them. However, seedling emergence was good (and normal), and plant growth effects of yellowing, leaf necrosis, and leaf tip burn were not observed until after a period exceeding 14 days had elapsed.

The greenhouse plants were forced to root in lime-treated soil only. In the field, lime is not uniformly mixed in the top soil, and the

plants root in the untreated subsoil as well. Perhaps an untreated subsoil experiment should be provided in greenhouse studies.

Potential problems of overwatering in greenhouse experiments exist, and according to Terman et al. (1966), possibly no completely satisfactory method of watering has been devised for experiments. The weighing method is the one most widely used. Terman et al. (1966) report that estimated 1/3 bar tension moisture level (approximately 2/3 field capacity) for soils to contain 18 to 30% moisture by weight for many soils. Estimated water percentage for near optimal growth for the Pond Creek soil used was 12.5%. Evenso, overwatering of plants in the sorghum experiment might be involved in failure of plants to respond to the lime application. But, why should untreated treatments show an advantage?

The high N rate of 180 lb N/A as urea used in the sorghum experiment might produce NH_3, which may cause seedling injury, reduce seedling establishment and reduce root extension (Allred et al., 1965). The N applied, being well mixed in the potted soil, did not exceed that rate per volume of soil involved given by Oklahoma State University as a rule of thumb regarding N and K application with seeds (Baker and Tucker, 1973) which often produce seed germination and seedling establishment problems. As indicated, no germination of seedling establishment problems were observed, however, shallow rooting of the sorghum plants, yellowing and leaf necrosis were noted. Cook (1962) reported damage to corn seedling roots when urea was the N source used. Phytotoxity of urea was also reported as a result of NH_3 released by Court et al. (1962).

Soil Exchangeable Ca and Mg

Application of lime rates to Pond Creek silt loam soil increased the exchangeable Ca significantly at 0.01 level of probability regardless of phosphorus rates (Table III). Comparison of LSD values with means indicate that both 0.7 and 1.4 tons/A lime rates increased exchangeable Ca (Figure 3).

Neither the lime nor phosphorus rates applied to Pond Creek silt loam soil had any effect on the exchangeable Mg (Table III).

Soil Exchangeable Al

Exchangeable Al in Pond Creek soil was reduced by application of lime. Without lime, the exchangeable Al values were 18 and 25 ppm for 20 and 60 lb/A P_2O_5, respectively (Table II). When lime rates were increased to 0.7, then to 1.4 tons/A combined with 20 lb/A P_2O_5, the exchangeable Al dropped to 13 ppm. The lime rates with 60 lb/A P_2O_5 also reduced the soil exchangeable Al to 13 ppm (Figure 4). Apparently, an increase of exchangeable Ca reduces the exchangeable Al drastically. Figure 4 shows that the 60 lb/A P_2O_5 rate had a higher exchangeable Al than 20 lb/A P_2O_5 with no lime and 0.7 tons/A lime rates. This is explained on the basis of KCl extraction solution with the addition of K_2HPO_4 and KCl as sources of K and P to Pond Creek soil might dissolve some of the Al-phosphate formed (Reed, 1980).

Soil pH

The initial Pond Creek soil pH is 5.3. Table II shows that addition of 20 or 60 lb/A P_2O_5 with no lime addition decreased the soil pH.

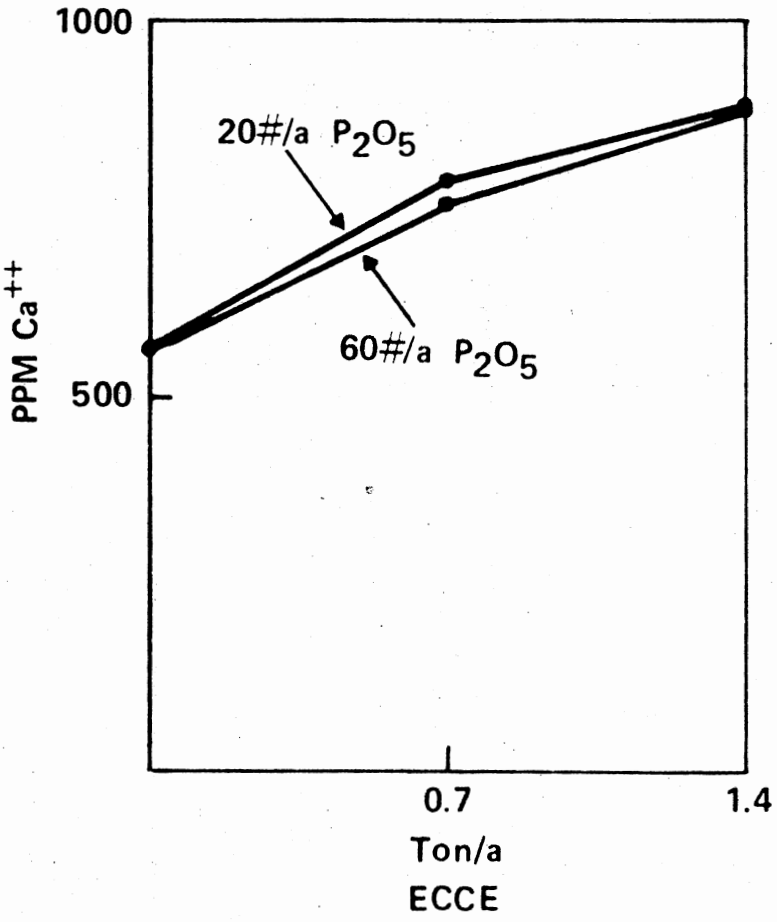

Figure 3. Effect of Lime and Phosphorus Rates on Exchangeable Ca on Pond Creek Soil.

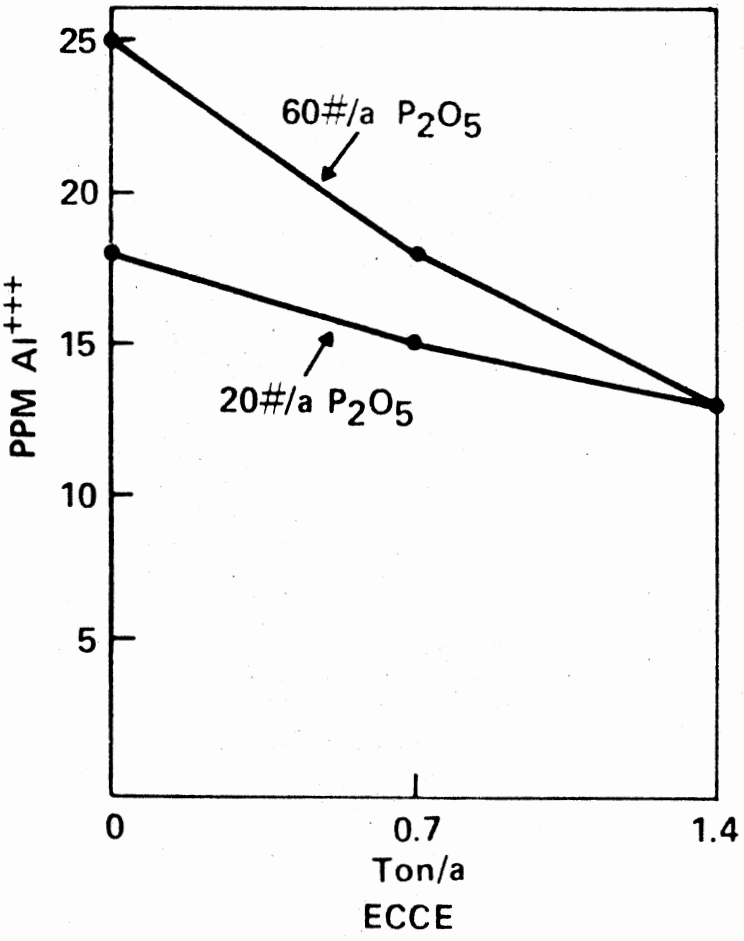

Figure 4. Effect of Lime and Phosphorus Rates on Exchangeable Al in Pond Creek Soil.

This is an apparent result of the hydrolysis of monocalcium phosphate in the soil as indicated by the following reactions (Black, 1968).

$$Ca(H_2PO_4)_2 \longrightarrow CaHPO_4 + H_3PO_4$$

$$4CaHPO_4 \longrightarrow Ca_4H(PO_4)_3 + H_3PO_4$$

$$5Ca_4H(PO_4)_3 + 4H_2O \longrightarrow 2Ca_{10}(OH)_2(PO_4)_6 + 3H_3PO_4$$

The highest pH value reached by lime application combined with phosphorus was 5.8 (Table II and Figure 5), which was far lower than that sought as shown by the Soil Test Laboratory recommendation and the soil titration curve.

The lower soil pH is apparently the combined result of insufficient soil lime reaction time, H ions resulting from the phosphate reversion reactions given above, hydrolysis and nitrification of urea-N added, producing H ions as per the following reactions (Tisdale and Nelson, 1975; Morrill, 1961; Morrill, 1980).

$$CO(NH_2)_2 + H_2O \longrightarrow (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 \longrightarrow 2NH_3 + H_2O + CO_2$$

$$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O$$

Crop removal of basic cations is possibly another reason for the low pH obtained in the sorghum experiment.

Reduction of yield and plant growth symptoms lead to suspicion of what is termed by the literature as overliming injury. Chlorotic leaves and poor root penetration, especially at the 1.4 tons/A lime rate, is in agreement with work reported by Pierre and Browning (1935), who ascribed the injuries of overliming to phosphate nutritional disturbances. Reduced phosphate availability by reversion was reported by Fox et al.

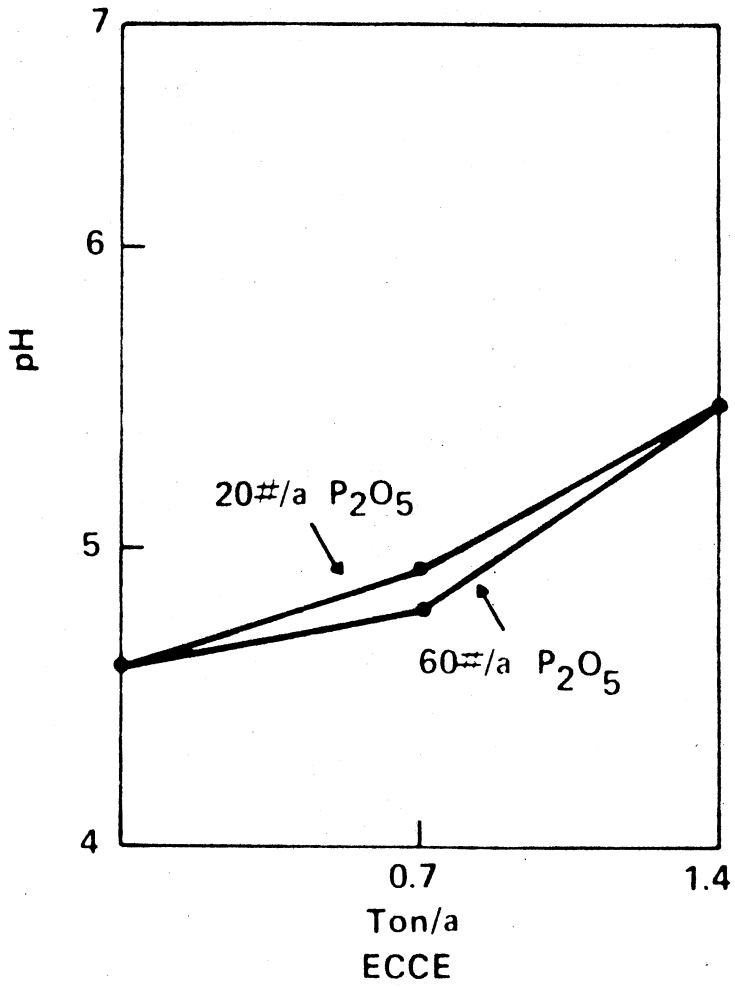

Figure 5. Effect of Lime and Phosphorus Rates on pH of Pond Creek Soil.

(1964) in a lime application test and other investigators report similar results (Gilbert, 1928; Mann, 1930; Knight, 1938).

A check on liming rate needed was made by titration of the Pond Creek soil with 0.01 N $Ca(OH)_2$. The results indicated that the 1.4 tons/A lime rate for this soil is approximately 500 lbs above that required to make the soil pH adjustment intended (Figure 6).

Wheat Experiment

Soil pH, Ca, Mg, and K

Enterprise fine silt loam soil was used for the second greenhouse experiment. Its initial pH was 5.1 as shown in Table I. Soil tests showed this soil to be high in available P_2O_5 and K_2O and, hence, wheat would likely not show a response to application of either. Six lime rates were applied to increase the soil pH up to 6.1 for the highest rate (Table IV and Figure 7).

The addition lime rates were desired to investigate soil-lime-crop response under greenhouse conditions in more detail since sorghum experiments, performed earlier, gave unexpected results.

As expected, soil exchangeable Ca increased with increased lime application rates, though not with a uniform slope. Statistical analysis showed significant exchangeable Ca changes for all lime rates (Table IV). The soil pH was lower at the time the wheat was harvested than expected, perhaps an insufficient time lapse was allowed for complete reaction with the soil acidic components. However, significant (0.01 level) pH changes were achieved (Table V).

Mg and K levels were not affected by liming. More than sufficient amounts of K being present initially in the soil makes changes difficult

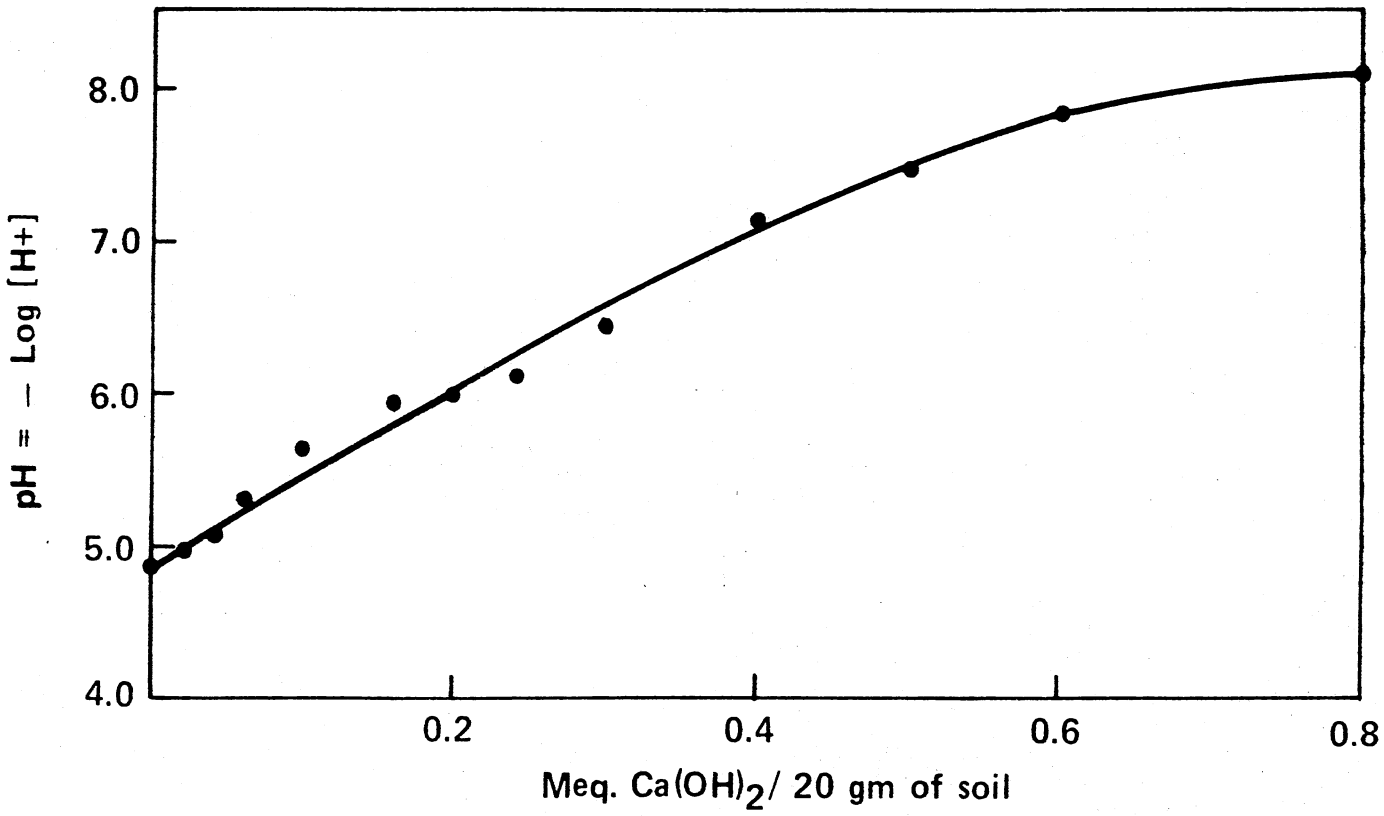

Figure 6. The Titration Curve for Pond Creek Silt Loam Soil.

TABLE IV

MEANS OF pH, Fe, EXCHANGEABLE Ca, Mg, K, Al, AND P OF ENTERPRISE FINE SILT LOAM SOIL AFTER LIME TREATMENT

Lime Rate (lb/A ECCE)	pH	Fe (PPM)	Ca (meq/100 g)	Mg (meq/100 g)	K (meq/100 g)	Al (PPM)	P (lb/A)
L_0 = no lime	5.1*	4.75	0.8	0.4	0.2	14	171
L_1 = 365	5.2	4.36	0.9	0.3	0.1	12	165
L_2 = 520	5.3	5.00	1.2	0.4	0.2	10	164
L_3 = 545	5.7	4.38	1.4	0.3	0.1	4	169
L_4 = 1023	5.6	4.75	1.5	0.3	0.1	6	172
L_5 = 1500	6.1	4.38	1.8	0.3	0.2	6	164
LSD (0.05)	0.2	----	0.1	---	---	2.9	---

*Means of 6 treatments.

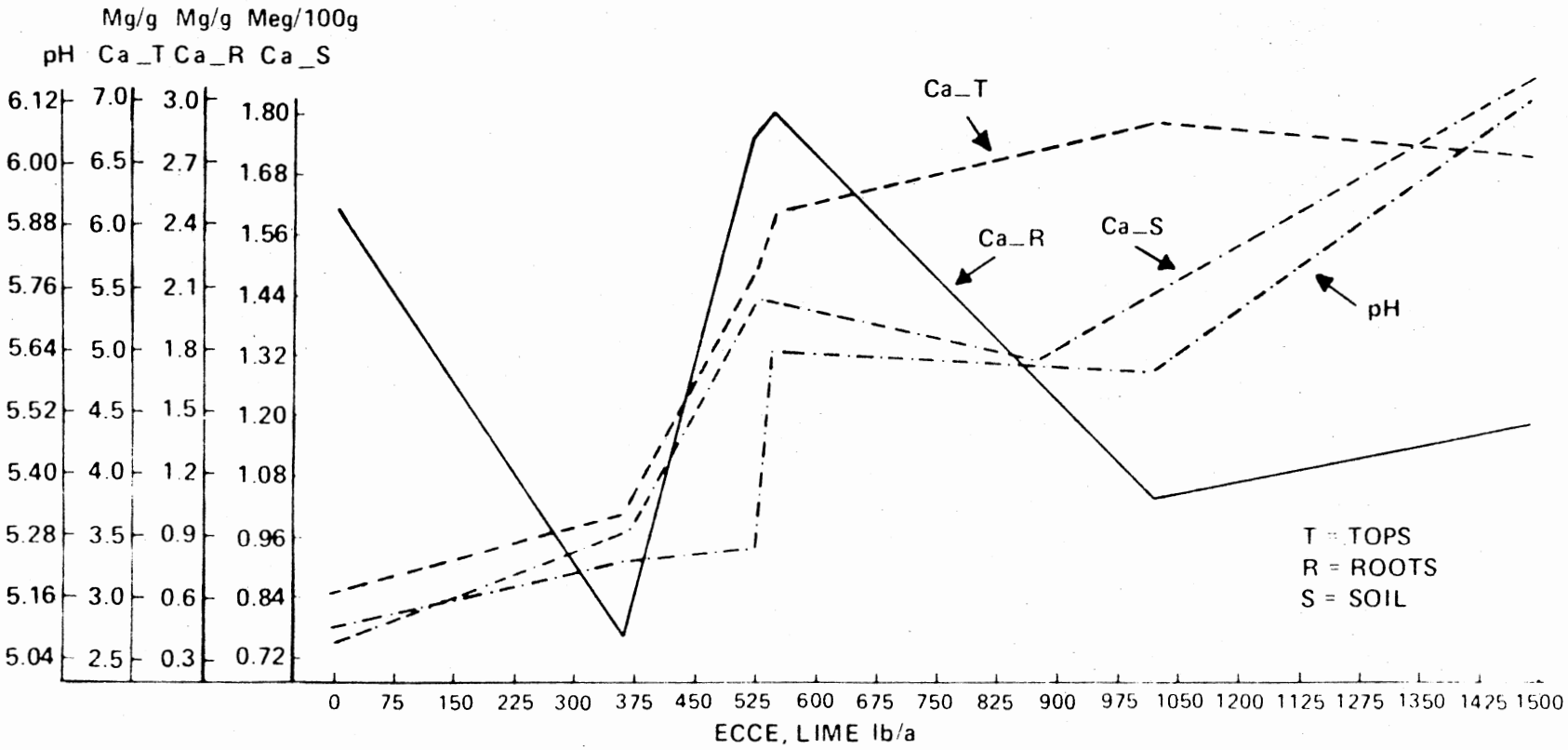

Figure 7. Effect of Lime on Enterprise Soil Exchangeable Ca, pH, Ca Contents of Wheat Tops and Roots.

TABLE V

MEAN SQUARES FOR pH, Fe, EXCHANGEABLE Ca, Mg, K, Al, AND P OF ENTERPRISE FINE SILT LOAM SOIL AFTER LIME TREATMENT

Source of Variation	pH	Fe (PPM)	Ca	Mg (meq/100 g)	K	Al (PPM)	P (lb/A)
Lime (lb/A)	0.829**	0.428	0.786**	0.005	0.001	90.383**	62.983

**Significant at 0.01 level of probability.

to detect. However, the exchangeable K should have increased, according to Jenny and Shade (1934), or decreased, according to MacIntire et al. (1930).

The latin square design was recommended to evaluate row and column (north-south and east-west) effects in the greenhouse. When the cans were set above the table top, approximately 7 inches, no row and column effects were noted except for K at the 0.05 level of probability. The significance of the K effect for rows and columns is difficult to interpret in this experiment. Perhaps other experimental designs would be more efficient for the study of liming effects in the greenhouse for future work when the plants are raised approximately 14 inches above the table top.

Soil Exchangeable Al, Soil Fe, and P

Liming had a significant effect on decreasing exchangeable Al, but did not measurably affect Fe and P. A decrease in exchangeable Al is in agreement with the recorded work of many investigators as noted by Bear (1964). Table IV shows the measured soil Al decreases gradually to the 520 lb/A lime rate, above which a larger decrease was noted, and a leveling off above at the 545 lb/A lime rate (Figure 8). This point corresponds with some rapid changes in pH, and Ca shown in Figure 7. McLean and Marshall (1948) have reported rapid changes when the soil reaches 70 to 75% Ca saturation of the exchangeable complex. Failure to measure changes in Fe and P is probably a result of their high values initially, as indicated by Baker and Tucker (1973).

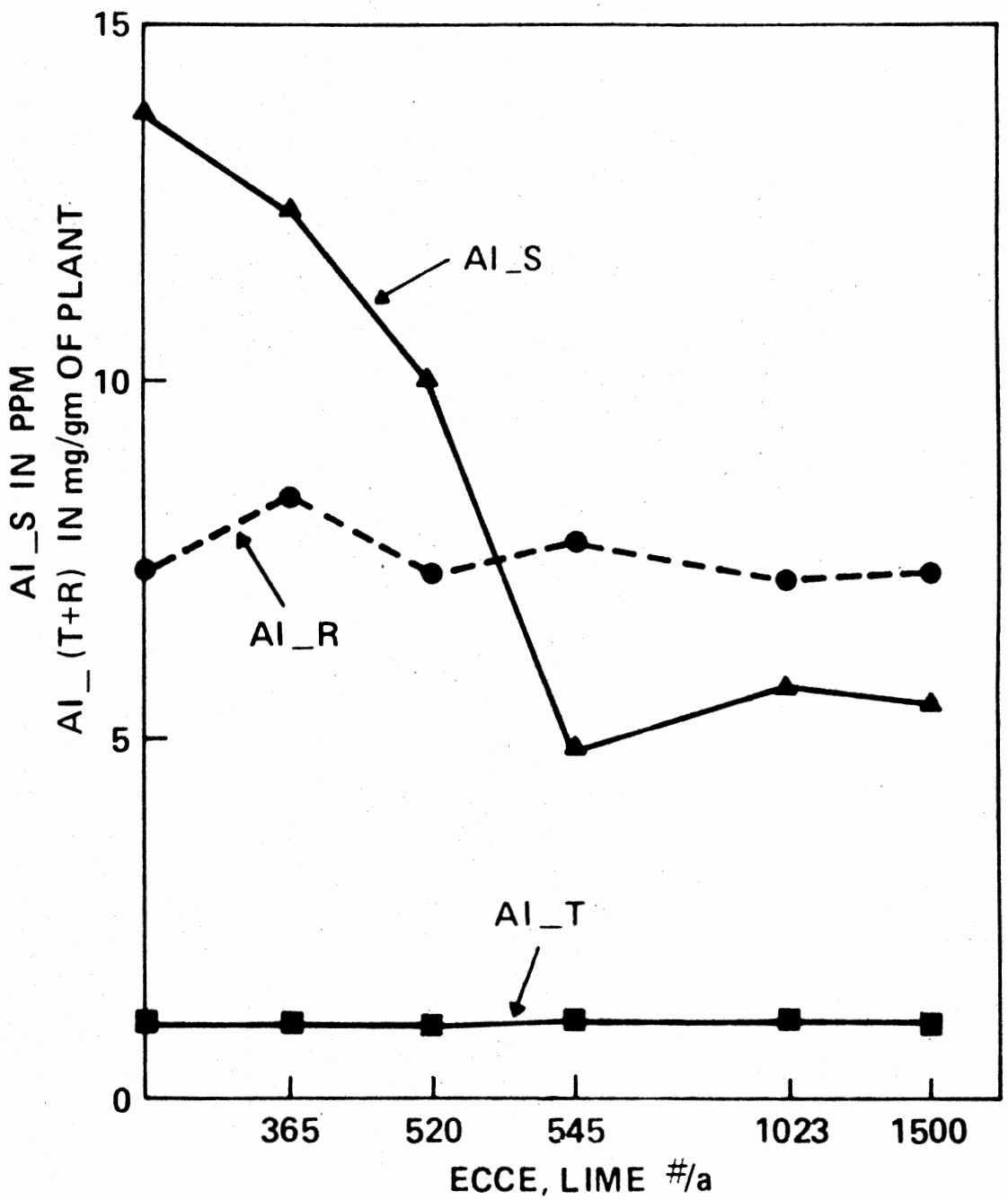

Figure 8. Effect of Lime on Aluminum in Enterprise Soil and in Wheat Tops and Roots.

Fresh and Dry Weights of Harvested Wheat Tops and Roots

Liming of the Enterprise fine silt loam soil caused significant (0.01 level) changes in fresh and dry weights of wheat tops, but had no significant effect on fresh and dry weights of roots. The fresh and dry weights of tops were increased to the 520 lb/A lime rate, then decreased at the higher liming rates (Tables VI and VII).

The wheat top growth response to added lime to the 520 lb/A lime rate should be expected. A decrease at all rates above this rate was not expected as indicated earlier in relation to the sorghum experiment, since responses to higher rates have been obtained in the field (Westerman and Associate, 1980). At least two suspect difficulties were eliminated from the wheat experiment, overwatering and too high of a N rate. Wheat roots in all treatments extended throughout the 3 kg of soil used. The results are almost as unexpected as for the sorghum experiment, eventhough a response to added lime was obtained for low rates, and indicate the need for better greenhouse techniques if field responses are to be characterized by greenhouse experiments. The effect of reaction time (soil-lime) prior to planting needs investigation. Also, use of an untreated subsoil layer should be included in an experiment.

Ca, Mg, K, Fe, P, and Al Contents of Wheat Tops

Ca contents of wheat tops were significantly (0.01 level) increased by liming throughout all liming rates. Mg contents were also significantly (0.05 level) increased or decreased corresponding with wheat top

TABLE VI

MEAN SQUARES FOR FRESH, DRY WEIGHTS, Fe, Ca, Mg, K, Al, AND P CONTENTS OF WHEAT TOPS AFTER LIME TREATMENT

Source of Variation	Tops Fresh Weight (g)	Tops Dry Weight (g)	Fe (mg/g)	Ca (mg/g)	Mg (mg/g)	K (mg/g)	Al (mg/g)	P (mg/g)
Lime (lb/A)	26.261**	0.455**	0.129	14.482**	0.207*	39.973	0.018	0.644

*Significant at 0.05 level of probability.

**Significant at 0.01 level of probability.

TABLE VII

MEANS OF FRESH AND DRY WEIGHTS AND CONTENTS OF Fe, Ca, Mg, K, Al, AND P OF WHEAT TOPS AFTER LIME TREATMENT

Lime Rate (lb/A ECCE)	Tops Fresh Weight (g)	Tops Dry Weight (g)	Fe (mg/g)	Ca (mg/g)	Mg (mg/g)	K (mg/g)	Al (mg/g)	P (mg/g)
L_0 = no lime	16.2*	2.0	0.9	3.1	3.4	59.2	1.0	5.5
L_1 = 365	17.8	2.2	0.8	3.7	3.0	60.1	1.0	5.5
L_2 = 520	20.2	2.6	1.2	5.6	3.4	57.3	1.1	5.4
L_3 = 545	18.3	2.3	1.1	6.1	3.4	63.8	1.1	5.9
L_4 = 1023	17.9	2.3	0.9	6.8	3.3	59.7	1.2	5.1
L_5 = 1500	14.0	1.8	0.9	6.5	3.1	56.3	1.1	6.0
LSD (0.05)	2.7	0.3	n.s.	1.1	0.3	n.s.	n.s.	n.s.

*Means of 6 treatments.
n.s. - not significant

yield. Needed Mg for every facet of vigorous plant growth and antagonism with high Ca levels are possible causes (Epstein, 1972).

K, Fe, P, and Al contents of wheat tops were not affected significantly by liming. Initial over sufficiency of K, Fe, P, and very low rates of Al transferred to wheat tops (see Figure 8) are likely causes for the noted lack of sensitivity.

Ca, Mg, K, Fe, P, and Al Contents of Wheat Roots

Liming of the Enterprise fine silt loam had no appreciable effect on Ca, Mg, K, Fe, P, and Al contents of wheat roots. This nonsignificant effect corresponds with that of root fresh and dry weights (Tables VIII and IX). It is noteworthy, however, that root Al contents were approximately sevenfold that of the tops (see Tables VII, IX, and Figure 8).

TABLE VIII

MEAN SQUARES FOR FRESH AND DRY WEIGHTS AND CONTENTS OF Fe, Ca, Mg, K, Al, AND P OF WHEAT ROOTS AFTER LIME TREATMENT

Source of Variation	Root Fresh Weight (g)	Root Dry Weight (g)	Fe (mg/g)	Ca (mg/g)	Mg (mg/g)	K (mg/g)	Al (mg/g)	P (mg/g)
Lime (lb/A)	0.672	0.099	0.982	6.275	0.633	5.924	0.302	0.532

TABLE IX

MEANS OF FRESH AND DRY WEIGHTS AND CONTENTS OF Fe, Ca, Mg, K, Al, AND P OF WHEAT ROOTS AFTER LIME TREATMENT

Lime Rate (lb/A ECCE)	Root Fresh Weight (g/5 plants)	Root Dry Weight (g/5 plants)	Fe (mg/g)	Ca (mg/g)	Mg (mg/g)	K (mg/g)	Al (mg/g)	P (mg/g)
L_0 = no lime	2.7*	1.0	4.6	2.5	2.0	17.7	7.4	2.6
L_1 = 365	2.4	0.9	5.6	0.4	1.9	17.5	7.5	2.7
L_2 = 520	2.7	1.1	5.8	2.8	2.3	16.2	7.8	2.2
L_3 = 545	2.4	0.9	5.2	2.9	2.4	16.6	7.8	2.5
L_4 = 1023	2.9	1.2	5.5	1.1	2.4	14.9	7.2	2.0
L_5 = 1500	2.0	0.8	5.4	1.4	2.6	16.4	7.4	2.2

*Means of 6 treatments.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two greenhouse studies were initiated in the Soil Fertility greenhouse at Oklahoma State University. The two studies involved liming of Pond Creek silt loam soil (Udic Argiustoll) with three rates of lime combined with two rates of phosphorus, and liming of Enterprise fine silt loam soil (Typic Ustochrept) with six rates of lime. Forage sorghum and winter wheat as plant indicators were grown on Pond Creek and Enterprise soils, respectively. The objectives of these studies were: to study the effect of lime application on the soil test value for Ca, K, Mg, P, Fe, and Al in soils, uptake of the same elements by wheat plants, and to study the effect of lime application on growth and yield of sorghum and wheat plants.

Data showed that lime application to Enterprise fine silt loam first increased the fresh and dry weights of wheat tops, then decreased weights at higher rates of lime without affecting the root growth. Lime rates combined with phosphorus rates applied to Pond Creek silt loam soil, decreased the fresh and dry weights of sorghum tops.

Liming both Pond Creek and Enterprise soils showed an increase in pH and exchangeable Ca, but did not affect the exchangeable Mg and K.

A significant decrease in measured Al was noticed on both soils after liming. On the contrary, wheat Al contents in wheat tops and

roots were not affected. This may be an indication of Al tolerance of the wheat variety used.

Subsequent titration of Pond Creek soil against 0.01 N $Ca(OH)_2$ shows that the highest liming rate proposed for this soil was higher than that required to obtained pH 6.4.

Unavailability of P and overwatering problems were possibly causes for obtaining unexpected low fresh and dry weights on Pond Creek soil.

The nonlinearity of lime application rates versus pH change, exchangeable Ca, and soil Al changes has been brought to our attention by this work, especially at 70 to 75% Ca saturation of soil colloids.

These experiments emphasize the need for application of lime to correct low soil pH-related problems, and to the need for better greenhouse methodology, especially with respect to overwatering and lime-soil reaction time, prior to and after planting. Since rooting of plants in these studies was restricted to lime-treated soils and rooting of crop plants in the field is not restricted to limed portions only, experiments investigating rooting and untreated subsurface layers should be considered for greenhouse study. This is brought to focus by work of Newton (1979) on Pond Creek soil where liming at rates used in this study or higher produced consistent crop yield increases. Furthermore, the reaction time after liming and before planting for greenhouse studies needs to be extended and more treatments at lower liming rates included. Failure of soils to reach the expected pH values as per Soil Test recommendation and soil titration via $Ca(OH)_2$ further indicates that a time delay is needed. These studies also brought to our attention the need for better control of greenhouse watering.

The results obtained in these studies should not be translated as expected field results, but rather that additional greenhouse work is required for Oklahoma soils before greenhouse results are representative of field responses to lime applications.

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VITA[2]

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